Simplified Metrics for the Identification of the Madden-Julian Oscillation in Models

Kenneth R. Sperber
Lawrence Livermore National Laboratory

Daehyun Kim
Lamont-Doherty Earth Observatory of Columbia University

Climate Model Metrics Panel Request for a Simple MJO Metric

In January 2011, the WGNE/WGCM Climate Model Metrics Panel **(Peter Gleckler** – co-chair) approached the MJO Task Force[1] (MJOTF) to request a simple metric for assessing the quality of the MJO in climate and forecast models. Given that conventional diagnostics were deemed too complex by the Climate Model Metrics Panel, the goal of the MJOTF was to develop a simple metric for assessing MJO fidelity that was consistent with the more complicated diagnostics developed by the CLIVAR MJO Working Group[2] (MJOWG).

[1]MJO Task Force (2009-present): E. Maloney (co-chair), M. Wheeler (co-chair), X. Fu, J. Gottschalck, D. Kim, J.-Y. Lee, H. Lin, R. Neale, M. Satoh, **K. Sperber**, A. Vintzileos, D. Waliser, S. Woolnough, P. Xavier, and C. Zhang. Former Members: H. Hendon, D. Raymond, and F. Vitart

[2]CLIVAR MJO Working Group (2006-2009): **K. Sperber** (co-chair), D. Waliser (co-chair), J. Gottschalck, H. Hendon, W, Higgins, I.-S. Kang, D. Kim, E. Maloney, M. Moncrieff, K. Pegion, N. Savage, S. Schubert, W. Stern, A. Vintzileos, F. Vitart, B. Wang, W. Wang, K. Weickmann, M. Wheeler, S. Woolnough, and C. Zhang

Background

MJO Characteristics and Teleconnections

- Dominant mode of subseasonal variability in the tropics
- Eastward propagating convection (Indian Ocean to the central Pacific)
- ~30-70 day time scale
- Strongest during boreal winter
- During boreal summer there is also a northward propagating component over India and Southeast Asia
- Affects convection over the eastern Pacific and Africa
- Influences the development of hurricanes and typhoons
- Impacts the development of some El Nino events
- Influences rainfall and temperature over the United States

MJO Simulation and Improvement Efforts

- Poorly represented in the vast majority of GCM's (Slingo et al. 1996, …, Zhang et al. 2005, …, Kim et al. (2009)
- Reflects the poor simulation of large-scale organized convection
- MJO improved through the addition of convective inhibition processes (*i.e.*, imposing larger minimum CAPE thresholds before releasing the convective instability, improving the representation of downdrafts and rain re-evaporation, etc.)
- However, in many cases these changes adversely affect the mean climate (Kim et al. 2011)
- The MJOTF is working on process-oriented diagnostics to better understand why the MJO is poorly represented in models
- The MJOTF, the CLIVAR Asian-Australian Monsoon Panel (**Ken Sperber** – co-chair), and GEWEX-GASS are investigating MJO case study simulations to diagnose MJO in models
- CINDY/DYNAMO 2011 observational campaign is critical for improved understanding of MJO processes, including its initiation over the Indian Ocean

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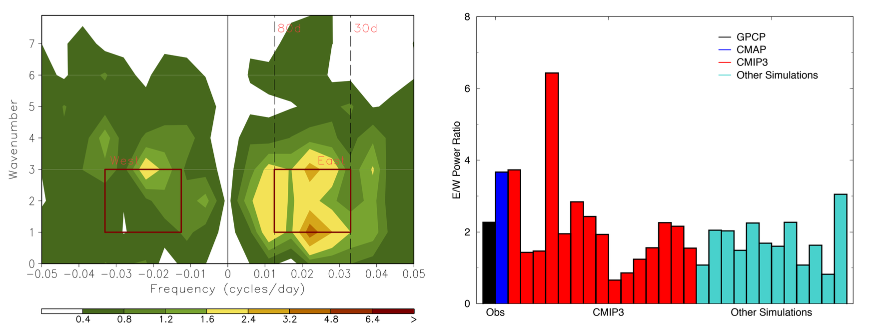
Conventional Diagnostics and Metrics

The MJOWG (**Ken Sperber** - co-chair) lead the development of MJO diagnostics for assessing the fidelity of MJO simulation (CLIVAR MJOWG 2009, *J. Clim.*, 22, 3006-3029, doi: 10.1175/2008 JCLI2731.1) and Kim et al. 2009, *J. Clim.*, 22, 6413-6436, doi: 10.1175/2009JCLI3063.1). One insightful approach was to use frequency-wavenumber decomposition of near-equatorial rainfall to evaluate eastward vs. westward propagation as a function of spatial scale.



The left figure shows the frequency-wavenumber decomposition of Global Precipitation Climatology Project (GPCP) rainfall for November-April 1997-2008 (x10^{-2} mm^2 day^{-2}). The largest power is for eastward propagation at wavenumbers 1-3 for time scales of 30-80 days. The right figure shows the East/West power ratio, calculated by dividing the sum of the eastward propagating power by the westward propagating counterpart for the afore-mentioned MJO wavenumbers and frequencies. The East/West power ratio is a conventional metric used to assess if eastward propagating variability dominates in the MJO frequency band. The analysis includes 15 Coupled Model Intercomparison Project-3 (CMIP3) simulations of the Climate of the 20th Century (1961-1999), 8 simulations from Kim et al. (2009), and two pairs of simulations using CAM and GFDL models to evaluate MJO sensitivity to changed convective processes (Kim et al. 2011). The East/West power ratios indicate that the majority of models underestimate the East/West power ratio, even given the observational uncertainty of this metric.

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Simplified metrics for the identification of the Madden–Julian oscillation in models

Kenneth R. Sperber[1]*† and Daehyun Kim[2]
[1]*Program for Climate Model Diagnosis and Intercomparison, Lawrence Livermore National Laboratory, Livermore, CA 94550, USA*
[2]*Lamont-Doherty Earth Observatory of Columbia University, 61 Route 9W, Palisades, NY 10964-1000, USA*

**Correspondence to: K. R. Sperber, Program for Climate Model Diagnosis and Intercomparison, Lawrence Livermore National Laboratory, P.O. Box 808, L-103, Livermore, CA 94550, USA. E-mail: sperber1@llnl.gov*

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Abstract

We propose simplified metrics to evaluate the fidelity with which the Madden–Julian oscillation (MJO) is simulated in climate models. These metrics are based on lag correlation analysis of principal component time series (PCs). The PCs are obtained by projecting simulated 20–100 day bandpass filtered daily outgoing longwave radiation onto the two leading empirical orthogonal functions of observed MJO variability. The simplified MJO metrics, the maximum positive correlation and time lag at which it occurs, provide consistent information relative to more complex diagnostics developed by the Madden–Julian Oscillation Working Group (CLIVAR MJOWG) and by Kim *et al*. Copyright © 2012 Royal Meteorological Society

Keywords: **Madden–Julian oscillation; climate models; metrics**

1. Introduction

We are at a unique time in the history of climate modeling, as two comprehensive databases of simulations are openly available to the modeling and analysis communities for understanding processes, validation against observations, and for the assessment of potential impacts of anthropogenic climate change (Taylor *et al*., 2012). The newly available Coupled Model Intercomparison Project-5 (CMIP-5) simulations are just being released and represent the state of the art in climate modeling as of 2011, while the CMIP-3 database represents the capability of models that were available *ca* 2005.

In the interest of assessing how model performance has changed between these two generations of models, the Working Group on Numerical Experimentation (WGNE) and the CLIVAR Working Group on Coupled Models (WGCM) have established the WGNE/WGCM Climate Model Metrics Panel (http://metrics-panel.llnl.gov/wiki/FrontPage). This panel is seeking recommendations for a standard set of climate and variability metrics for routine application to new climate simulations (it is anticipated that computer code to calculate the simple Madden–Julian oscillation (MJO) metrics will be posted on the Metrics Panel website in the near future). These metrics are expected to be easily calculated and understood by a broad community, including nonspecialists, and provide an initial indication of the fidelity with which climate and variability are simulated. Given the importance of the MJO in weather and climate variability (Liebmann *et al*., 1994; Takayabu *et al*., 1999) the WGNE/WGCM Climate Model Metrics Panel asked the Year of Tropical Convection Madden–Julian Oscillation Task Force (YOTC MJOTF) to recommend simple metrics for evaluating the MJO in climate model simulations (Sperber, 2011, pers. comm.).

The YOTC MJOTF deliberated the appropriateness of candidate metrics through teleconferences and in face-to-face meetings. The ensuing spirited debate prompted the validation of these simple metrics against more complex level-2 diagnostics developed by the CLIVAR MJO Working Group (CLIVAR MJOWG, 2009) and by Kim *et al*. (2009), including frequency-wavenumber decomposition and Wheeler and Hendon (2004) multivariate empirical orthogonal functions (EOFs). The goal of this paper is to present simple metrics that capture many of the salient features of the MJO, especially those related to the propagation of convection. The data used in this study are discussed in Section 2 and the description and application of the metrics are given in Section 3, with discussion given in Section 4.

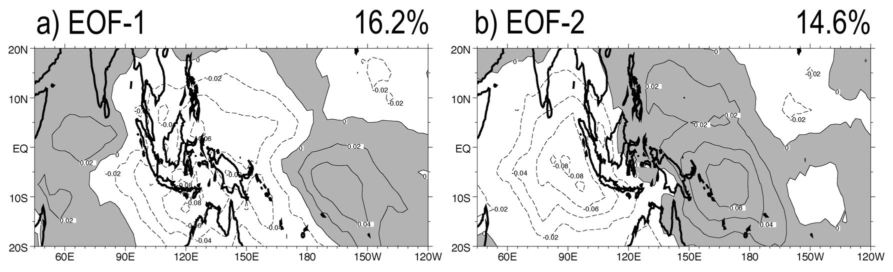
2. The data

In this study we use advanced very-high resolution radiometer daily outgoing longwave radiation

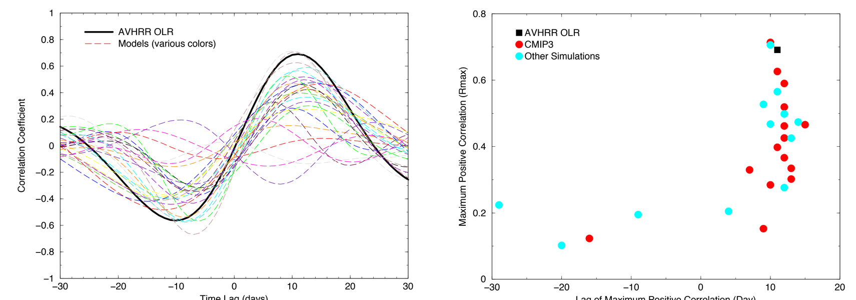
Simple Metrics

The simple metrics approach uses the protocol developed by **Sperber** et al. (2005). 20-100 day bandpass filtered outgoing longwave radiation (OLR) from the models is projected onto the two leading AVHRR OLR EOF's that describe the propagation of MJO convection (**Sperber** 2003). Projecting the model data onto the observed EOF's addresses the question: How well do the models simulate the observed MJO? Furthermore, the models need to be projected onto a standard set of basis functions in order to be able to make a direct quantitative comparison of performance.

a) EOF-1 16.2% b) EOF-2 14.6%



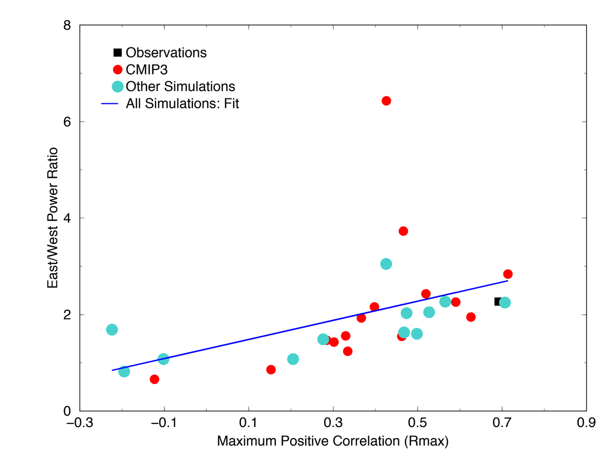
For each model, projecting the filtered OLR onto the observed EOF's results in one principal component (PC) time series for each EOF. The relationship between the PC's forms the basis of the simple metrics for assessing MJO fidelity. The lag correlation between of the two PC time series is calculated, with the maximum positive correlation and the time lag at which it occurs giving an indication of the "coherence" with which the propagation occurs, and an estimate of the MJO time scale, respectively.



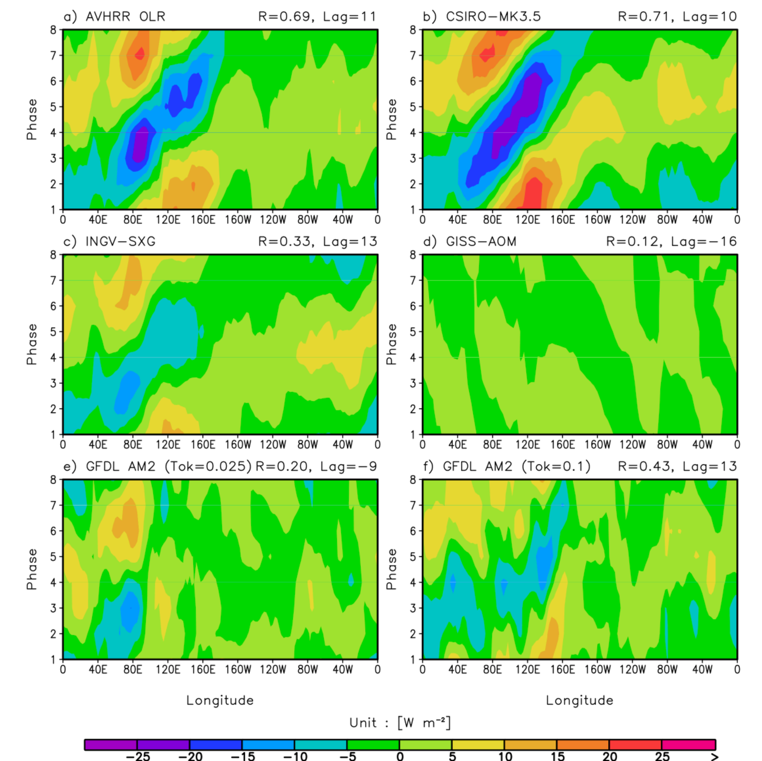
The left figure shows the lag correlation structure of the observations and the models. For positive time lags, PC-2 leads PC-1, indicating eastward propagation of convective anomalies. From this lag correlation structure, the right figure shows the maximum positive correlation vs. the time lag at which it occurs (also see table below). The majority of models have a transition time for convection from the Indian Ocean to the Maritime Continent that is consistent with observations (~11 days). However, their smaller maximum positive correlations indicate that the propagation is not as coherent as observed. Four models are incorrectly dominated by westward propagation. Additionally, the standard deviation of the PC's is a direct measure of the amplitude of the convective anomalies.

	OLR				Precipitation	
Model	R_{max}	Lag (days)	PC-1 std. dev.	PC-2 std. dev.	E/W Power Ratio	E^2/W Power (mm^2 day^{-2})
Obs (1979-2007)	0.69	11	197.81	200.35	2.27	0.29
BCCR-BCM2.0	0.47	15	184.65	205.94	3.73	0.46
CGCM3.1 (T47)	0.30	13	87.14	90.01	1.43	0.06
CGCM3.1 (T63)	0.28	10	87.89	82.79	1.47	0.05
CNRM-CM3	0.43	12	156.44	177.15	6.43	1.00
CSIRO-Mk3.0	0.63	11	188.45	174.92	1.95	0.07
CSIRO-Mk3.5	0.71	10	264.35	246.63	2.84	0.22
GFDL-CM2.0	0.52	12	142.00	153.01	2.43	0.19
GFDL-CM2.1	0.37	12	106.28	108.04	1.93	0.12
GISS_AOM	0.12	-16	32.98	32.65	0.66	0.01
FGOALS-g1.0	0.15	9	74.19	80.19	0.86	0.01
INGV-SXG	0.33	13	141.38	139.92	1.24	0.05
MIROC3.2(medres)	0.33	7	117.87	119.20	1.56	0.05
ECHO-G	0.59	12	251.88	235.87	2.26	0.29
ECHAM5/MPI-OM	0.40	11	174.53	205.29	2.16	0.29
MRI-CGCM2.3.2	0.46	12	146.01	113.21	1.55	0.06
CAM3.5	0.10	-20	160.24	160.37	1.08	0.07
CAM3z	0.53	9	163.78	141.70	2.05	0.20
CFS	0.47	14	163.94	133.02	2.03	0.28
CM2.1	0.28	12	107.76	101.26	1.49	0.11
ECHAM4/OPYC	0.71	10	245.59	216.70	2.25	0.24
GEOS5	0.22	-29	84.84	106.14	1.69	0.09
SNU	0.50	12	157.30	123.88	1.60	0.09
SPCAM	0.57	11	236.12	208.69	2.27	0.30
CAM3.1/RAS (evap=0.05)	0.20	4	118.38	101.84	1.08	0.05
CAM3.1/RAS (evap=0.6)	0.47	10	188.20	152.25	1.63	0.22
GFDL AM2 (Tok=0.025)	0.20	-9	104.08	104.33	0.82	0.04
GFDL AM2 (Tok=0.1)	0.43	13	129.44	105.29	3.05	0.54

Simple vs. Conventional Metrics

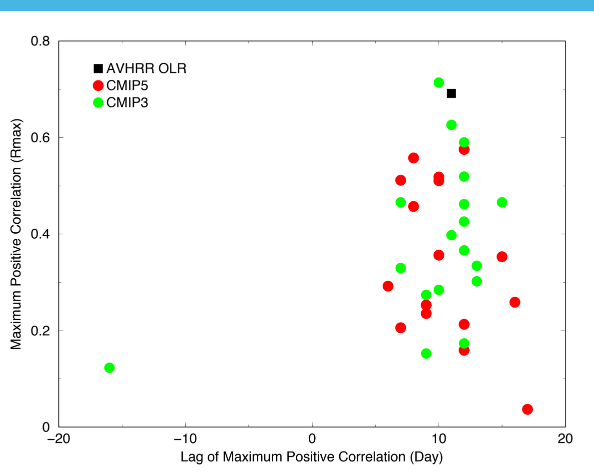


The figure above shows the maximum positive correlation vs. the East/West power ratio. The regression between the two metrics is significant at the 5% level, indicating that overall the simple metric gives results consistent with the more complex conventional metric. Further evidence that the simple metrics are consistent with more complex diagnostics is presented below.



The figure above shows the propagation of near-equatorial OLR anomalies from observations and models. The propagation characteristics, based on Wheeler and Hendon (2004) multivariate EOF's, are consistent with the simple metrics. For example, compared to observations, CSIRO-Mk3.5 has stronger and more coherent eastward propagation, consistent with its larger maximum positive correlation (MPC). Analogously, INGV-SXG has less coherent eastward propagation, and GISS-AOM has westward propagation. The MPC is also consistent with the improved eastward propagation in GFDL AM2 (Tok = 0.1) compared to GFDL AM2 (Tok = 0.025), indicating that modification of the convection scheme improves the MJO simulation.

New Results: CMIP5 vs. CMIP3



An analysis of 16 CMIP5 models (1961-1999) indicates no improvement in the simulation of the MJO compared to the CMIP3 models. The application of the more comprehensive MJOWG diagnostics to the CMIP5 simulations is needed to diagnose the shortcomings in more detail.